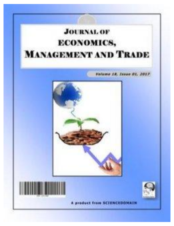

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Nitrogen and Phosphorus Fertilizer Micro-doses on Maize and Its Effect on Profitability: An Evidence from Sub-humid Farming Systems, Tanzania

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Authors' contributions

This work was carried out in collaboration between all authors. Author PSS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors FG, CLR, JMRS, AAK and LM managed the analyses of the study and read the draft manuscript. Authors KDM and SS managed the literature searches and read the draft manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Despite a high productive potential for many best bet agricultural technologies, there is a low rate of adoption from farmers. Recommendations of improved technologies such as fertilizer use based on agronomic data without economic analysis contributes to this low adoption rate. The purpose of this study was to evaluate the profitability of selected fertilizer types and rates in maize production in a sub-humid farming system. A field experiment was conducted to investigate costs and revenue of fertilizer types and rates applied on maize farms using a split-plot layout under randomized

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complete block design. The phosphate fertilizers trialed were local Minjingu Mazao (MM), di-ammonium phosphate (DAP) and triple super phosphate (TSP), urea was used to supply nitrogen. Fertilizer rates were micro-doses at 12.5%, 25%, 50% and 75% compared to control and recommended rates. Local MM at 75% micro-dosing produced the highest net benefit 3.0 – 3.5 million Tanzanian Shillings per hectare (TZS/ha) followed by 2.7 – 2.9 million TZS/ha from TSP at recommended rates and DAP at a 75% micro-dose rate under subsistence farming. Micro-dosing fertilizer at 25% and 50% produced the highest benefit-cost ratio under both commercial and subsistence farming conditions. Micro-dosing at a rate of 12.5% was more profitable than the control rate and farm profitability increased towards 25% and 50%, thereafter decreasing as application approached the recommended rate. Adoption of micro-dosing fertilizer at 12.5% could be an entry point to fertilizer use and to later be advanced to 25% and 50% micro-dosing rates which are more profitable under smallholder farming systems in sub-humid tropics.

Keywords: Benefit-cost ratio; fertilizer use; gross margin; revenue.

1. INTRODUCTION

Agriculture is the backbone of the economy in most developing countries as it provides the main source of food, feed, employment, raw materials for industry and foreign exchange earnings [1]. In Tanzania, agriculture employs 65.5% of people, contributes 100% to the national food supply (when there is adequate rainfall) and 29.1% of gross domestic product [2] and [3]. Cereals such as maize and rice are the most important crops grown for food and cash in sub-Saharan African (SSA) countries, including Tanzania [4,5,6]. Maize accounts for 50% of the calories and protein consumed in Eastern and Southern Africa and generates about 50% of rural cash income in Sub Saharan Africa [7].

Despite a high productive potential for many best bet agricultural technologies there is a low rate of adoption. This results in low productivity for most food and cash crops, of about 30% of potential yield [8]. Low maize yields, for instance 1.0 – 1.7 t/ha in SSA compared to the potential 7.5 – 8.2 t/ha [9] is attributed mainly to declining soil fertility caused by very low fertilizer application, averaging 19 kg/ha in Tanzania [2] - 38% of African Union's Abuja Declaration [10]. Nitrogen and Phosphorus fertilizers have been recommended for use in various parts of Tanzania [11]. Fertilizer micro-dosing, a technology of reduced application rates (25 – 33% of the recommended rate [12] and [13]) has been reported to increase crop yields in semi-arid areas of West Africa [14] and [15]. In Sub Saharan sub-humid and semi-arid agro-climates the maize yield attained from micro-dosing was found to be twice that of zero fertilizer application [16] and [17]. Recommendations of improved fertilizer application technologies normally target an optimum production rate. However, purchasing enough fertilizer to achieve these application rates may not be economically feasible for poor farmers.

Economic analysis therefore is very important and enhances the usefulness of biophysical research results [18]. Smallholder farmers are highly aware of the prices of labour and inputs (such as seeds, fertilizers and pesticides). Hayashi et al. [19] reported more profit from farmers applying inorganic fertilizers than without fertilizer application in millet cropping. However, Bachmann et al. [20] reported that lower net profit of micro-dosing fertilizer as compared to recommended rates in maize production might limit its adoption. Lessons on the economy of fertilizer micro-dosing technology can further be drawn from different country case studies [12,19,15], however more contributions to the debate on how soil fertility can be revitalized are still needed [21]. Therefore, study of the cost components of micro-dose based maize production under agronomic experiments will help understand costs and could increase profitability. Thus, the objective of this paper is to evaluate the profitability (gross margin, return to labor and benefit-cost ratio) of selected fertilizer types and their micro-dose rates in maize production in a sub humid farming system.

2. MATERIALS AND METHODS

2.1 Study Area and Experimental Treatments

Field experiments were carried out in Ilakala and Changarawe villages of Kilosa District, Morogoro Region in Tanzania during the 2015 and 2016 cropping seasons. Three phosphate fertilizers - namely Di-ammonium Phosphate (DAP), Minjingu Mazao (MM) and triple super phosphate

(TSP) - were applied at planting and urea fertilizer was applied at vegetative growth stage for maize to supplement nitrogen [11]. Different fertilizer micro-dose rates at 12.5%, 25%, 50% and 75% were applied and compared with zero fertilizer application as well as the recommended rates (100%) in maize [17], whereby, a TMV-1 variety was used as test crop [22].

2.2 Data Collection

Information on costs of inputs such as seeds and fertilizers was collected from agro-shops during procurement of these materials. Labor costs for commercial farming and quantity of human labor (man-days per ha) under subsistence farming for land preparation, planting, fertilizer application, weeding, harvesting, shelling, transport and storage of produce respectively were collected during execution of the entire experimentation (Table 1). Commercial and subsistence farming systems have been distinguished by Waceke and Kimenju [23]. Subsistence farming is a form of farming in which crops or livestock are raised to sustain the farm family. Subsistence farmers are not endowed with financial resources to buy inputs and very rarely hire labor as most activities are carried out by family members. Commercial farming is a type of farming in which farmers, endowed with financial resources to buy inputs and acquire hired labor or implements to perform farm activities, maximize crop production.

Yield of produce (kg/ha) was obtained from a split-block designed farm trial [17] and corresponding results are presented in Fig. 1. Moreover, prices of produce in case study sites were collected during harvest and sowing from a total of 15 local key informants including project research assistants, village agriculture extension officers and, in particularly, subsistence farmers. The minimum price was collected during harvest and the maximum price at sowing period. The average price is a reflection of the overall prices considering all prices during both harvesting and sowing seasons (Fig. 1).

From this data, gross return (GR), total variable cost (TVC) gross margin (GM) (or net profit), return from labor and benefit-cost ratios (BCR), were calculated using the following equations [24]:

$$Gross\ Return = Yield\ of\ produce\ \times\ its\ market\ price \tag{1}$$

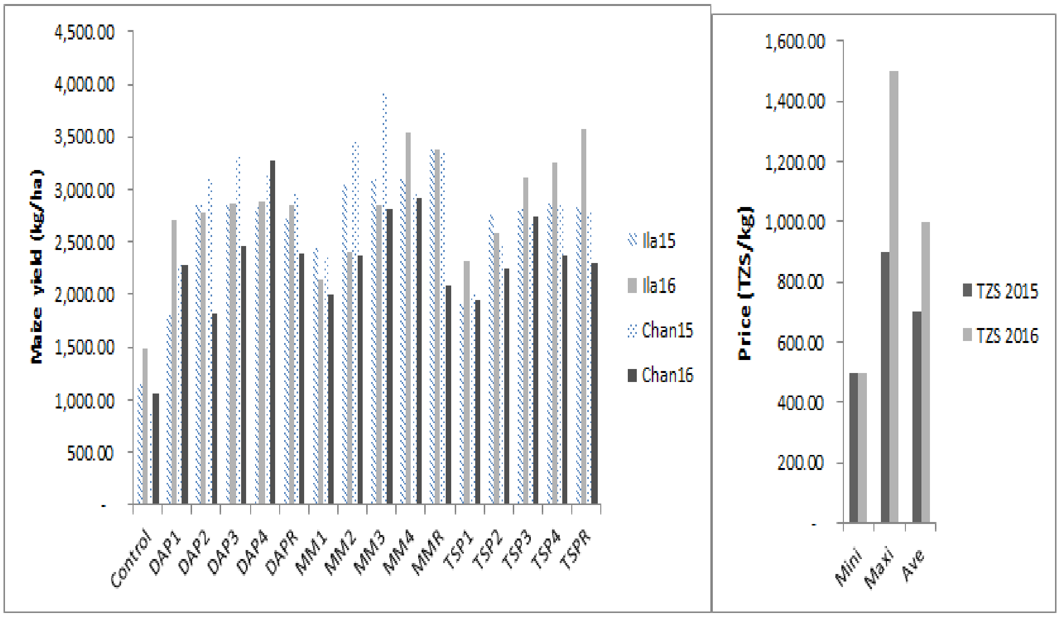
$$Gross\ Margin = Gross\ Return - Total\ Variable\ Costs \tag{2}$$

$$Return\ to\ labor = \frac{(Goss\ Return - Total\ Variable\ Costs)\ per\ ha}{Number\ of\ persondays\ per\ ha} \tag{3}$$

$$Benefit - Cost\ ratio = \frac{Gross\ Return}{Total\ Variable\ Cost} \tag{4}$$

Table 1. Costs of inputs and labor in field activities under commercial and subsistence farming

Item/ Activity	Unit	Cost or labor power
Seeds	TZS per ha	62,500.00
Fertilizer- DAP	TZS per 50 kg bag	75,000.00 – 80,000.00
Fertilizer- MM	TZS per 50 kg bag	35,000.00
Fertilizer- TSP	TZS per 50 kg bag	60,000.00
Fertilizer- Urea	TZS per 50 kg bag	55,000.00- 60,000.00
Cultivation (Non- family labor)	TZS per ha	125,000.00
Cultivation (family labor)	Man-days per ha	35.00
Planting (Non- family labor)	TZS per ha	75,000.00
Planting (family labor)	Man-days per ha	7.81
Fertilizer application (Non- family labor)	TZS per ha	75,000.00
Fertilizer application (family labor)	Man-days per ha	6.25
Weeding twice (Non- family labor)	TZS per ha	200,000.00
Weeding twice (family labor)	Man-days per ha	33.75
Harvesting (Non- family labor)	TZS per ha	87,500.00
Harvesting (family labor)	Man-days per ha	6.56
Shelling (Non- family labor)	TZS per ha	60,000.00
Shelling (family labor)	Man-days per ha	7.50
Storage bags (woven/ polythene)	TZS per bag	1,200.00
Transportation of produce to home	TZS per bag	1,500.00



Key: DAP, MM and TSP are Di-ammonium phosphate, Minjingu mazao and Triple super phosphate fertilizers;
Numbers 1 to 4 are micro-dose rates 12.5, 25, 50 and 75% of recommended nitrogen and phosphorus;
R is a recommended rate 40 kg P and 80 kg N/ha in maize.
Ila is Ilakala and Chan is Changarawe site, 15 and 16 are cropping years 2015 and 2016
TZS is Tanzani Shillings, Mini is minimum, Maxi is maximum, and Ave is average

Fig. 1. Maize grain yield (kg/ha) and prices (TZS/kg) during 2015 and 2016 cropping seasons

3. RESULTS

3.1 Revenue and Costs of Fertilizer Use in Maize Production

The lowest gross return was noted in control plots while the highest returns were due to fertilizer application from Ilakala and Changarawe study areas during 2015 and 2016 (Table 2). Gross return increased from control to micro-dose rates in DAP and thereafter decreased as application approached the recommended rate (DAP5). The trend of DAP was similar with Minjingu Mazao (MM) and triple super phosphate (TSP) with few exceptions at Ilakala where gross return increased to recommended rates in MM during 2015 and TSP during 2016 as shown in Table 2. The highest gross return in both sites was recorded from MM3 (2.7 million TZS/ha) and MM5 (2.3 million TZS/ha) during 2015, while in 2016 MM4 and TSP5 (3.5 million TZS/ha) attained the highest gross returns in Ilakala and DAP4 (3.2 million TZS/ha) in Changarawe during 2016.

Total variable costs in both commercial and subsistence farming increased with fertilizer application rates and types (Table 2). Fertilizers, TSP and DAP, had more total variable cost than MM in both commercial and subsistence systems, however, the cost of commercial farming is 500,000 Tanzanian shillings (TZS/ha) greater than subsistence farming as far as fertilizer application is concerned. Fertilizer application had more labor demand than on control farms but farming as per fertilizer micro-doses and recommended rates had equal labor (man-days) demand in spot application (Table 2).

3.2 Gross Margin of Fertilizer Rates in Maize Production

Gross margin, that is also a net profit, from fertilizer types and rates was very high under subsistence farming compared to commercial farming with the highest profit in Minjingu Mazao (MM4) as presented in Fig. 2. Under commercial farming, the control had the lowest gross margin and during 2015 Changarawe had a net loss (or negative profit). Plots with application of DAP2 and DAP4, MM2, MM3 and MM4, TSP2, TSP3 and TSP5 had the highest gross margins (Fig. 2).

Table 2. Gross return, total variable costs and labor in maize fertilizer micro-dosing technology

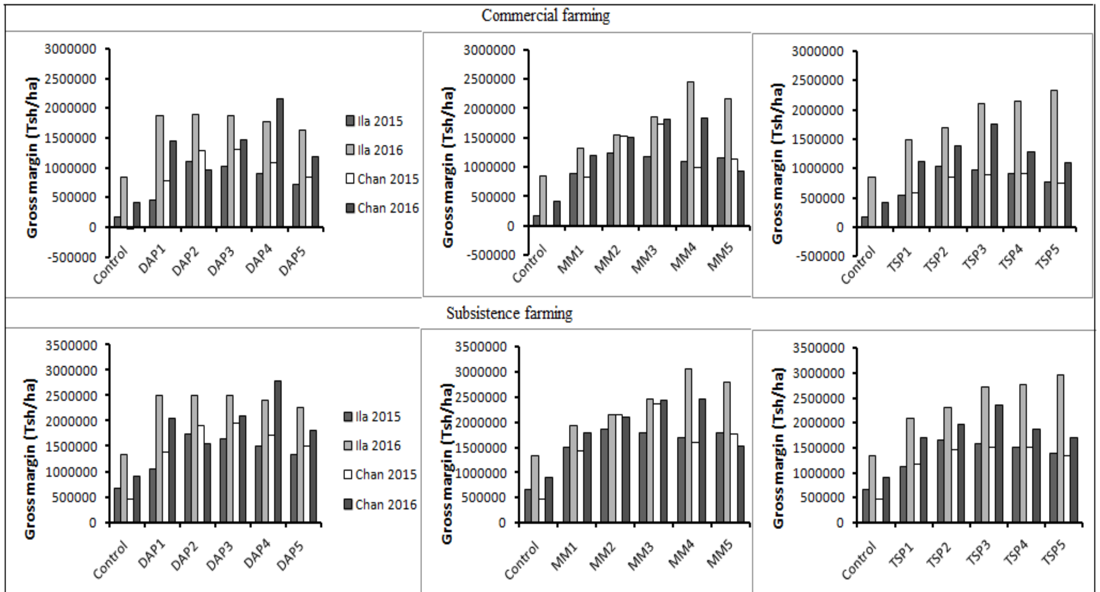
Treatment	Gross return (1000'TZS/ha)				TVC (1000'TZS/ha)		Labor
	GR Ilakala 2015	GR Ilakala 2016	GR Changarawe 2015	GR Changarawe 2016	TVC-Commercial	TVC-Subsistence	Person days/ha
Control	806.4	1492.0	611.8	1059.0	639.5	149.5	91
DAP1	1263.5	2715.0	1599.5	2277.0	819.9	223.9	97
DAP2	1997.1	2776.0	2184.0	1824.0	883.5	278.3	97
DAP3	2009.0	2864.0	2323.3	2466.0	997.1	372.3	97
DAP4	1983.8	2886.0	2197.3	**3270.0**	1107.5	473.7	97
DAP5	1904.7	2846.0	2067.8	2389.0	1206.0	575.1	97
MM1	1716.4	2146.0	1646.4	2003.0	817.6	221.1	97
MM2	2136.4	2415.0	2433.9	2379.0	883.4	270.9	97
MM3	2172.8	2844.0	**2737.0**	2805.0	991.8	371.2	97
MM4	2175.6	**3543.0**	2070.6	2924.0	1092.5	471.9	97
MM5	**2363.9**	3373.0	2340.1	2089.0	1191.8	573.3	97
TSP1	1354.5	2319.0	1406.3	1940.0	815.2	223.7	97
TSP2	1932.0	2579.0	1731.1	2253.0	882.3	277.9	97
TSP3	1971.2	3106.0	1887.9	2747.0	997.7	385.2	97
TSP4	2010.4	3258.0	2015.3	2372.0	1106.7	493.6	97
TSP5	1988.7	**3573.0**	1952.3	2300.0	1214.0	600.9	97

DAP, MM and TSP are fertilizer types namely Di-ammonium phosphate, Minjingu Mazao and triple super phosphate. Numbers 1, 2, 3, 4 and 5 are fertilizer rates as 7.5 kg P and 10 kg N, 10kg P and 20, 20 kg P and 40kg N/ha, 30 kg P and 60 kg N, and 40kg P and 80 kg N/ha. GR is gross return, and TVC is a total variable costs. Number bolded are highest GR

Table 3. Benefit cost ratio of maize from fertilizer micro-dosing

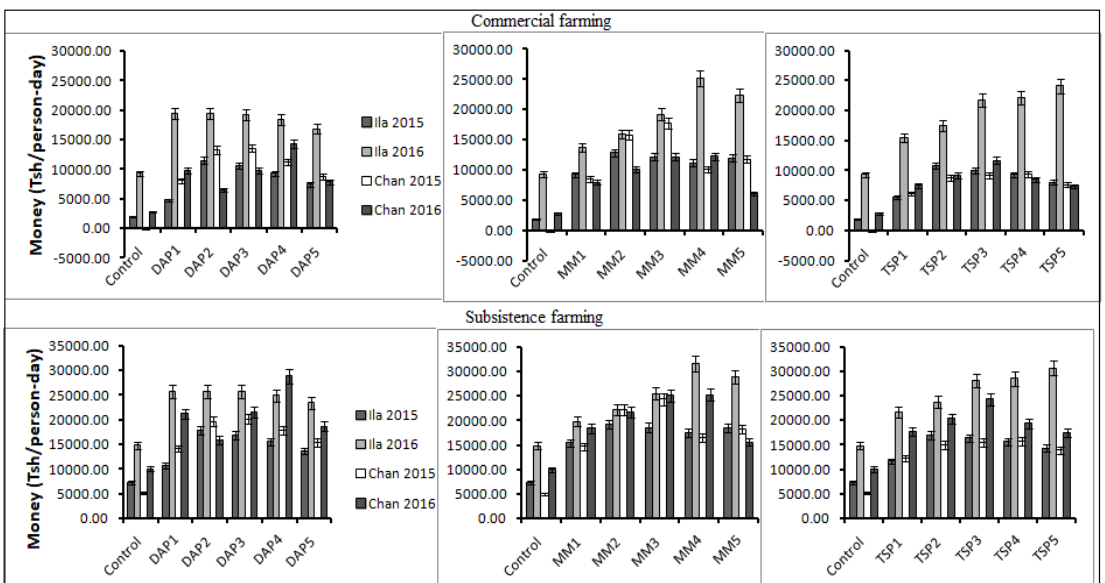
Treatment	BCR- commercial				BCR- subsistence			
	Ilakala 2015	Ilakala 2016	Changarawe 2015	Changarawe 2016	Ilakala 2015	Ilakala 2016	Changarawe 2015	Changarawe 2016
Control	1.27	2.30	0.96	1.66	5.39	9.98	4.09	7.08
DAP1	1.57	3.26	1.95	2.77	5.74	12.13	7.14	10.17
DAP2	2.26	3.12	2.43	2.12	7.37	9.97	7.85	6.55
DAP3	2.04	2.86	2.30	2.49	5.40	7.69	6.24	6.62
DAP4	1.83	2.60	1.97	2.92	4.19	6.09	4.64	6.90
DAP5	1.61	2.34	1.70	1.98	3.31	4.95	3.60	4.15
MM1	2.09	2.63	2.00	2.47	7.76	9.71	7.45	9.06
MM2	2.40	2.77	2.70	2.73	7.89	8.91	8.98	8.78
MM3	2.19	2.90	2.70	2.86	5.85	7.66	7.37	7.56
MM4	1.99	3.22	1.90	2.69	4.61	7.51	4.39	6.20
MM5	1.97	2.81	1.95	1.79	4.12	5.88	4.08	3.64
TSP1	1.67	2.82	1.73	2.39	6.05	10.37	6.29	8.67
TSP2	2.17	2.92	1.97	2.57	6.95	9.28	6.23	8.11
TSP3	1.98	3.09	1.90	2.76	5.12	8.06	4.90	7.13
TSP4	1.82	2.91	1.82	2.17	4.07	6.60	4.08	4.81
TSP5	1.64	2.90	1.61	1.92	3.31	5.95	3.25	3.83

DAP, MM and TSP are fertilizer types namely Di-ammonium phosphate, Minjingu Mazao and triple super phosphate. Numbers 1, 2, 3, 4 and 5 are fertilizer rates as 7.5 kg P and 10 kg N, 10kg P and 20, 20 kg P and 40kg N/ha, 30 kg P and 60 kg N, and 40kg P and 80 kg N/ha. GR is gross return, and TVC is a total variable costs



Key: DAP = Diammonium phosphate, MM = Minjingu mazao and TSP = Triple super phosphate; Numbers 1 to 5 are rates (10 kgN and 5 kgP; 20 kg N and 10 kg P; 40 kg N and 20 kg P; 60 kg N and 30 kg P; and 80 kg N and 40 kg P/ha)

Fig. 2. Gross margin of maize under fertilizer micro-dosing application



Key: DAP = Diammonium phosphate, MM = Minjingu mazao, TSP = Triple super phosphate; Numbers 1 to 5 = Rates (10 kg N and 5 kg P, 20 kg N and 10 kg P, 40 kg N and 20 kg P, 60 kg N and 30 kg P, and 80 kg N and 40 kg P/ha), Ila = Ilakala and Chan = Changarawe

Fig. 3. Return to labor in maize fertilizer micro-dosing technologies for 2015 and 2016 in Ilakala and Changarawe

3.3 Return to Labor in Maize under Fertilizer Application

Return to labor was higher in subsistence than commercial farming with the highest amount of money saved when applying Minjingu Mazao (MM4) as shown in Fig. 3. The control had the lowest value, with a negative return to labor at Changarawe during 2015 in commercial farming. There was an increase in costs per person-day from control to micro-dose rates with the increase declining as application approached recommended rates (Fig. 3).

3.4 Benefit-Cost Ratio of Fertilizer Micro-dose Rates in Maize Production

Commercial farming had lower benefit cost ratios (BCR) than subsistence. Maize commercial farming had the highest BCR in DAP2, DAP4 and MM2 with the lowest values on control plots (Table 3). Subsistence maize farming had the highest values in DAP1 and MM2 with a different trend when compared to commercial farming.

4. DISCUSSION

Gross return was influenced by the cost of resources invested (labor and inputs), quantity of crop produced and price fluctuation. The amount of maize crop produced per unit area varied among fertilizer types and levels applied as well as cropping year. These variations among treatments reflected the importance of fertilizer application to increase crop yield. Maize Prices fluctuated between seasons. During harvest the supply of maize was very high, resulting in a low price. At sowing, maize supply was very low for most smallholder farmers such that the value of maize increased extremely. The fluctuation of maize prices reported in this study followed a trend reported by Sodogo et al. [25] confirming the supply and demand theory described by Debertin [24]. Total production costs increased on plots treated with fertilizers due to extra expenses incurred purchasing fertilizers, transportation costs and the cost of labor needed to apply fertilizers [26]. Subsistence farming required some extra field activities such as cultivation, sowing, weeding, and fertilizer application. Harvesting is considered a routine responsibility for family members in subsistence farming systems as many other examples show [27]. Family labour often involves self-exploitation, not striving for a regular minimum salary and social benefits, but in exchange provides higher flexibility, self-determination, and relatively transparent profit-sharing [28]. This resulted into lower production costs when compared to commercial farming whereby every field activity was performed at a cost.

The net loss in control plots under commercial farming was caused by increased production costs in land which is not productive without fertilizer application. This indicates that whenever the farmer is shifting from subsistence to commercial production, fertilizers should be used more intensively, as noted also by other authors such as Pingali [29] and Waceke and Kimenju [23]. Fertilizer micro-dose rates of only 25%, 50% and 75% from the recommended nitrogen and phosphorus rates produced the highest net profit. This can be considered a strategy for coping with low rainfall periods or harsh weather conditions [30], declining soil fertility [31] and reducing fertilizer costs due to lower quantities purchased [12]. Results of net return reported in this study are different from those reported by Bachmann et al. [20] who found 16.9% lower net return in fertilizer micro-dosing rates of 55.3% compared to the recommended rate of NPK fertilizer. This difference can be attributed to differences in weather conditions such as 800 – 1100 mm rainfall. The resulting profitability follows a similar trend with those reported by Camara et al. [12] showing that micro-dosing had higher returns to investment when compared to recommended fertilizer application rates. Profitability analysis in terms of net profit, return to labor and benefit-cost ratio indicated that MM fertilizer was the most profitable followed by DAP and TSP. This is mainly due to the lower market price of MM fertilizer. Also, MM fertilizer application resulted in relatively higher yields compared to DAP and TSP that increased revenues. Fertilizer micro-dosing at 12.5%, 25% and 50% of recommended nitrogen and phosphorus application were more profitable than the recommended rates due to increasing yields with still lower amounts of fertilizer usage. Hence, these lower rates, for instance 223,900 TZS/ha for 12.5% fertilizer micro-dose rates are economically more viable for poor smallholder farmers in sub-humid tropical conditions.

5. CONCLUSION AND RECOMMENDATION

Market prices of maize fluctuated over the year, with the price during harvest being low and increasing towards the period of preparation for following cropping seasons. Minjingu Mazao fertilizer had the highest return among the phosphate fertilizer types under this study. A micro-dosing rate of 12.5% was more profitable than zero fertilizer application and the profitability increased for application rates of 25% and 50% and decreased at as application approached the recommended rate (100% N and P) in both subsistence and commercial farming. Subsistence farming was more profitable than commercial farming due to high labor charges. Therefore, smallholder farmers should first adopt micro-dosing at 12.5% as a low-cost entry point to fertilizer use, and later on advance to 25% and 50% micro-dosing rates which are even more profitable. These micro-fertilization techniques can easily offset fertilizer costs and bring fairly high yields, profits and increase return on investment under changing weather conditions affecting crop production in sub-humid tropics.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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